DOCUMENT RESUME

ED 342 651 SE 052 544

AUTHOR O'Neil, John
TITLE Raising Our Sights: Improving U.S. Achievement in Mathematics and Science.
INSTITUTION Association for Supervision and Curriculum Development, Alexandria, Va.
REPORT NO ISBN-0-87120-187-9
PUB DATE 91
NOTE 50p.
AVAILABLE FROM Association for Supervision and Curriculum Development, 1250 N. Pitt Street, Alexandria, VA 22314 (Stock No. 611-91170: $6.50).
PUB TYPE Viewpoints (Opinion/Position Papers, Essays, etc.) (120)

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS Academic Standards; *Curriculum Development; Educational Change; *Educational Testing; Elementary Secondary Education; Instructional Development; *Instructional Improvement; *Mathematics Achievement; Mathematics Education; Mathematics Instruction; Science Instruction; Student Evaluation; Teacher Education
IDENTIFIERS *International Evaluation Education Achievement; *Science Achievement

ABSTRACT

Despite rising concerns about the mathematics and science achievement of U.S. students, a flood of evidence amassed over the past decade suggests that far too few students are receiving the high-quality education needed in these subjects either for careers or for basic citizenship. The Association for Supervision and Curriculum Development (ASCD) Panel on U.S. Achievement in Mathematics and Science was convened in May 1991 to examine three issues: (1) the continued low standing of U.S. students on international mathematics and science achievement tests; (2) the possible reasons for this low standing; and (3) the changes needed to improve U.S. mathematics and science achievement. The report is presented in three sections. Section 1 discusses the nature of the problem, indicating that low achievement is evident at all levels from primary through secondary school. Section 2 discusses the possible causes for low U.S. achievement, concluding that too few students receive sufficient instruction in mathematics and science in grades K-12 to achieve desired levels. The effects of tracking, the impact of underrepresented groups, outmoded theory and practice, and working conditions are also discussed. In section 3, the panel gives recommendations for improving U.S. achievement in mathematics and science in the areas of Curriculum, Standards, Assessment, Teacher Preparation, and Public Support. An executive summary states the panel's findings and enumerates its recommendations. Among the specific recommendations are the following: (1) all students should be required to take mathematics and science throughout their precollegiate education; (2) the development of international standards should be supported; (3) assessment programs should include "performance tasks"; and (4) emergency licensing of teachers in mathematics and science should be eliminated. (62 references) (MDH)

ED342651

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

X This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY

R. Brandt

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

SE 052 544

BEST COPY AVAILABLE

ISSUES
ANALYSIS

RAISING OUR SIGHTS

IMPROVING U.S. ACHIEVEMENT IN MATHEMATICS AND SCIENCE

JOHN O'NEIL
FOR THE
ASCD PANEL
ON U.S.
ACHIEVEMENT
IN
MATHEMATICS
AND SCIENCE

Copyright 1991 by the
Association for Supervision
and Curriculum Development
1250 N. Pitt Street
Alexandria, VA 22314
(703) 549-9110

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system without permission in writing from the publisher.

Printed in the United States of America.

ASCD Stock No.: 611-91170
ISBN: 0-87120-187-9

Library of Congress Cataloging-in-Publication Data

O'Neil, John.
Raising our sights : improving U.S. mathematics and science achievement / [John O'Neil for the ASCD Panel on U.S. Achievement in Mathematics and Science].
p. cm.—(Issues analysis)
Includes bibliographical references (p.).
ISBN 0-87120-187-9 : $6.50
1. Mathematics—Study and teaching—United States—Evaluation.
2. Science—Study and teaching—United States—Evaluation.
3. Academic achievement—United States—Evaluation.
I. ASCD Panel for U.S. Achievement in Mathematics and Science.
II. Title. III. Series.
QA13.055 1991
510.7'1073—dc20 91-32235
CIP

Raising Our Sights: Improving U.S. Achievement in Mathematics and Science

Members of the ASCD Panel on U.S. Achievement in Mathematics and Science . . iv

Introduction: Cause for Concern v

1. What is the Problem? 1

2. What are the Causes of Low U.S. Achievement? 6

3. Recommendations for Improving U.S. Achievement in Mathematics and Science 18

Appendix: Executive Summary 30

References 35

Members of the ASCD Panel on U.S. Achievement in Mathematics and Science

John Bishop, Associate Professor, Cornell University, Ithaca, New York

Audrey Champagne, Professor of Education and Chemistry, State University of New York-Albany, New York

Dennis Cheek, Coordinator of Curriculum Development, New York Science, Technology and Society Education Project at the State Education Department and Facilitator of the ASCD Network for Science, Mathematics, and Technology Education, Albany, New York

Dorothy Gilford, Director, Board on International Comparative Studies in Education, National Academy of Sciences, Washington, D.C.

Nancy Mead, Project Director, International Assessment of Educational Progress, Educational Testing Service, Princeton, New Jersey

Dorothy Strong, Director of Mathematics, Chicago Public Schools, Chicago, Illinois

Diane Berreth (Liaison and Chair), Deputy Executive Director, Association for Supervision and Curriculum Development, Alexandria, Virginia

Gordon Cawelti (Ex-officio), Executive Director, Association for Supervision and Curriculum Development, Alexandria, Virginia

John O'Neil (Principal Author), Editor, Association for Supervision and Curriculum Development, Alexandria, Virginia

Introduction: Cause for Concern

"Current mathematics achievement of U.S. students is nowhere near what is required to sustain our nation's leadership in a global technological society."
—Mathematical Sciences Education Board

"At the very moment in history when science and technology touch American lives more deeply than ever before, there is compelling evidence that only a small percentage of the students who pass through the schools develop any useful scientific understanding."
—National Center for Improving Science Education

Despite rising concerns about the mathematics and science achievement of U.S. students, a flood of evidence amassed over the past decade suggests that far too few students are receiving the high-quality education needed in these subjects either for careers or for basic citizenship.

Consider the following troubling indicators of the United States' underachieving system of mathematics and science education:

- Only half of U.S. 12th graders are able to successfully answer questions calling for "reasoning and problem solving involving fractions, decimals, percents, elementary geometric properties, and simple algebraic manipulations"; only one in 20 can answer questions calling for "reasoning and problem solving involving geometric relationships, algebraic equations, and beginning statistics and probability." In science, only 7 per-

cent of 17-year-olds "can infer relationships and draw conclusions using detailed scientific knowledge," and the performance of this age group lags well behind that posted two decades ago (Mullis and Jenkins 1988; Mullis, Dossey, Owen, and Phillips 1991; Mullis, Owen, and Phillips 1990).

- A greater percentage of secondary students enroll in remedial or below-grade mathematics courses than the combined percentages of students who enroll in trigonometry, analysis/pre-calculus, or calculus. One-half of students take no chemistry and four in five take no physics. Black and Hispanic students are substantially less likely than white students to take advanced coursework in mathematics and science (Kolstad and Thorne 1989).
- As many as one-fourth of all college freshmen are taking remedial courses in mathematics (Madison and Hart 1990) and 60 percent of all college mathematics enrollments are in courses ordinarily taught in high school (National Research Council 1989). More than one-half of all U.S. doctorates in mathematics and engineering, one-third in physics, astronomy, and computer sciences, and one-quarter in life sciences are awarded to foreign students (Madison and Hart 1990, Thurgood and Weinman 1990).
- U.S. businesses spend as much for remedial training in mathematics as is spent on mathematics education at all levels from elementary schools through higher education (National Research Council 1989).
- Nearly two-thirds of U.S. adults are incapable of reading and comprehending a newspaper or magazine story about a current scientific or technological controversy, and fewer than 10 percent, one expert says, can reasonably be considered scientifically literate (Miller 1991).

Among the key factors accounting for the low achievement of U.S. students in science and mathematics are the curriculum and instructional and material resources available to students (as well as their propensity to take advantage of them). Curriculums are often ill-conceived and repetitious, textbooks overstuffed, teachers overburdened and (particularly in elementary school) underprepared, classrooms lacking in needed equipment, and students

either tracked out of or disinclined to take high-level courses. The low number of U.S. students mastering high levels of material in mathematics and science, some research suggests, reflects our entrenched belief that skills in these fields are the domain of a few, and that "natural talent," rather than effort, is the key to success (Stevenson, Lee, and Stigler 1986).

During the 1980s, a period of intense concern over educational quality in the United States, few indicators of U.S. student achievement garnered the interest of policymakers and pundits as successfully as the results of international testing in mathematics and science. In the aftermath of *A Nation at Risk* (National Commission on Excellance in Education 1983), with its dire warning about the mediocre quality of U.S. schools, the comparatively poor standing of the United States on mathematics and science tests gave rise to numerous suggestions for policy changes, as well as observations about how cultural variables may affect achievement. Some of the reaction to international assessments may well prove fruitful, but U.S. educators and policymakers would do well to avoid simplistic "solutions" (Purves 1989). The ASCD Panel on U.S. Achievement in Mathematics and Science was convened in May 1991 to examine three issues: (1) the continued low standing of U.S. students on international mathematics and science achievement tests, (2) the possible reasons for this low standing, and (3) the changes needed to improve U.S. mathematics and science achievement. This analysis is based on the panel's deliberations and recommendations.

1
What Is the Problem?

"By the year 2000, U.S. students should be first in the world in mathematics and science."

—President George Bush

"When compared with students of other nations, U.S. students lag far behind in mathematical and scientific accomplishment."

—Mathematical Sciences Education Board

Whether the goal is primacy in the world in mathematics and science achievement or helping students acquire the mathematics and science literacy needed to survive in an increasingly technological society, the results of several international assessments leave little to hearten U.S educators and the public. Almost without exception, U.S. students achieved, at best, a middle ranking compared to their counterparts in selected nations. This standing holds true across content and grade level from arithmetic to calculus, earth science to physics, elementary school students to high school seniors. At its worst, the achievement of U.S. students on certain topics and at certain ages ranks at the bottom among nations participating in various international assessments.

As part of the Second International Mathematics Study (SIMS), which tested students' mathematics achievement in 8th and 12th grade in some 20 countries during the early 1980s, the United States scored in the midrange or worse on almost all measures (McKnight et al. 1987). In a more recent assessment of five countries and four Canadian provinces (three of which assessed two

different language groups) carried out by the Educational Testing Service (ETS), U.S. 13-year-olds posted the lowest average score in mathematics. Only 40 percent of U.S. students were able to use intermediate mathematics skills to solve two-step problems, for example, compared to 78 percent of students in Korea, the highest scoring nation (LaPointe, Mead, and Phillips 1989).

In science, the picture is similar. Of more than a dozen nations taking part in the Second International Science Study (SISS), the United States ranked no higher than eighth in the world for any age group or subject tested. In biology (the most commonly taken high school science course), the United States finished dead last. The ETS study confirmed the low standing of U.S. students, with U.S. 13-year-olds finishing close to the bottom of 12 populations tested in science achievement (LaPointe et al. 1989).

Low Achievement Across the Board

Conventional wisdom notwithstanding, one can take little solace in the notion that U.S. achievement results reflect the fact that some other countries' education systems are more explicitly selective as students progress through the system. This argument, frequently made, suggests that U.S. students are not competing on a level field because *all* U.S. students—the top, average, and lowest achievers—are competing against the "best and brightest" other nations have to offer. But this is an incomplete explanation at best.

For example, at the 8th grade level, where students from all participating nations remained in school, the U.S. students' performance in the SIMS maintained its mediocre standing (McKnight et al. 1987); the ETS' study, likewise, found U.S. 13-year-olds underachieving in mathematics and science (LaPointe et al. 1989). Moreover, a cross-national study of mathematics achievement in 20 5th grade classrooms at each of three sites—Sendai (Japan), Taipei (Taiwan), and Minneapolis, Minn. (U.S.)—found that the highest scoring American classrooms obtained an average score lower than that of the lowest-scoring Japanese classroom and all but one of the 20 classrooms in Taiwan (Stigler, Lee, and Stevenson 1990).

Moreover, the mathematics and science achievement gap between U.S. students and their international peers persists across the achievement spectrum: it cannot be laid at the feet of our average pupils or slower learners. In the SIMS, the performance of the top 5 percent of U.S. students was matched by the top 50 percent of students in Japan, and the top 1 percent of U.S. students scored the lowest of the top 1 percent of any other participating nation (McKnight et al. 1987, National Research Council 1989). SISS reported that the 24 percent of Norwegian and 11 percent of Australian 18-year-olds taking their second year of physics had a higher mean score than the 1 percent of U.S. students taking their second year of the subject (International Association for the Evaluation of Educational Achievement 1988).

Nor is it always accurate to assume that the generally greater cultural and racial homogeneity of other nations gives them an advantage over the more diverse United States. Stigler and Stevenson (1991) point out in their comparison of American, Chinese, and Japanese elementary schools that although the United States is more *culturally* diverse, it is variation in educational backgrounds among students within classrooms that poses the most challenge to teachers. In this respect, Asian students are just as variable as those in the United States. "It is wrong to argue that diversity within classrooms is an American problem," they assert. "Teachers everywhere must deal with students who vary in their knowledge and motivation."

There are, of course, important exceptions to the relatively low performance of U.S. students in mathematics and science. American physics students at the 1989 International Physics Olympiad brought home the gold medal, and in 1990, two U.S. members won bronze medals (*Science Education News* 1991). Finalists in the annual U.S. Westinghouse National Science Talent Search are second to none in the world in their grasp of mathematics and science (Phares 1990). Competitions such as these show that there are bright spots in U.S. mathematics and science achievement—oases in the midst of parched ground.

What Are the Stakes?

Much has been written and said about the relationship between the performance of the U.S. education system, particularly in mathematics and science, and the success of the United States in an increasingly competitive global economy. Trimming the trade deficit will, in part, depend upon U.S. expertise in mathematics, science, and technology, some experts assert. It will depend upon raising the achievement level of the increasing numbers of students needed for careers involving mathematics and science and also increasing the mathematic and scientific literacy of students who may not specialize but nonetheless need broad understanding to thrive on the job or in society. The ability to do world-class work in these fields means much more to the individual student than enlarging corporate coffers or bringing about a favorable trade balance. As more good jobs require competence in mathematics and science, those students who become mathematically or scientifically literate will increase their chances of going on to college or securing good jobs (Johnston and Packer 1987). Raising, or even maintaining, the standard of living for today's and tomorrow's students will require that they obtain a thorough grounding in mathematics and science in grades K-12.

A recent report published by the College Board (Pelavin and Kane 1990) bears out the relationship between the mathematics and science courses students take in high school and their chances of attending college—and points out particular implications for minority students. For blacks and Hispanics (who are presently less likely to take advanced mathematics or science courses or to score highly on achievement tests), developing skill in mathematics and science can be a catapult to higher education and careers. The College Board notes that minorities presently attend college at only 70 percent of the rate of white students. But among students who take geometry, the gap between college-going black, Hispanic, and white students virtually disappears. Eighty percent of black students, eighty-two percent of Hispanic students, and eighty-three percent of white students who take a high school course in geometry go on to college. Taking algebra or a laboratory science course also relates to above-average college-going rates, although these courses are not as accurate a predictor as geometry.

Whether or not students attend college, their future jobs will increasingly depend on solid grounding in mathematical and scientific skills. "Mathematical and scientific literacy form the basis of technological expertise in the workplace," says *Everybody Counts*, the 1989 report of the National Academy of Sciences. "In tomorrow's world, the best opportunities for jobs and advancement will go to those prepared to cope confidently and competently with mathematical, scientific, and technological issues" (National Research Council 1989).

In a broader sense, mathematical and scientific literacy has become even more crucial to developing a citizenry capable of making informed judgments. As public policy issues increasingly involve scientific and technological issues, "the preservation of democratic governments in the 21st Century may depend on the expansion of the public understanding of science and technology" (Miller 1991). Discussions of health and environmental issues are "impossible without using the language of mathematics; solutions to these problems will require a public consensus built on the social fabric of literacy" (National Research Council 1991). Whether interpreting the findings of a bar graph printed in a newspaper or following the latest controversy over medical ethics, informed citizens must routinely call upon the skills and knowledge developed in mathematics and science courses.

2

What Are the Causes of Low U.S. Achievement?

Numerous causes have been suggested to explain the low achievement of U.S. students on national and international assessments of mathematics and science knowledge. This panel identified the following factors, in particular, as most deserving mention:

Far too few U.S. students receive sufficient instruction in mathematics and science in grades K-12 to achieve at desired levels. This problem is particularly acute among underrepresented populations.

At no stage of pre-collegiate education in the United States—elementary, middle, or secondary—do the majority of U.S. students receive the comprehensive instruction in mathematics and science needed for most or all to achieve at high levels.

At the elementary level, there is evidence that science, in particular, may be a victim of "curricular squeeze." Notes one educator: "If you set out on a journey to discover where we teach elementary science, you might easily visit thousands of schools without finding a single room designed with science in mind" (McKenzie 1990). The Council of Chief State School Officers (CCSSO) reports that U.S. elementary students average, at best, 36 minutes a day of science instruction and 59 minutes of mathematics (Blank and Dalkilic 1991). Both the curriculum and the common instructional practices in U.S. mathematics and science elementary classrooms, moreover, have been criticized as needlessly repetitious and oriented toward rote learning (McKnight et al. 1987, National Research Council 1989).

Graduation requirements within the states permit many students, especially the non-college bound, to earn a diploma with

little advanced coursework in mathematics and science. Fewer than a dozen states require students to take at least 2.5 to 3 Carnegie units each of science and mathematics to graduate (Blank and Dalkilic 1991). Moreover, requirements can sometimes be fulfilled by watered-down general courses (Clune, White, and Patterson 1989).

The learning of advanced topics in mathematics and science is far from universal among U.S. students. Although an estimated 88 percent of U.S. students take a course in biology and 76 percent take a first course in algebra, percentages of students taking other advanced mathematics and science courses are considerably lower (see Figure 2.1). These figures, moreover, do not reflect school dropouts, about whose academic work little is known. Even though the United States retains a higher percentage of students through graduation than some other nations, its advanced mathematics enrollments are only about average (McKnight et al. 1987). And SISS

Figure 2.1

Percentages of High School Graduates Taking Selected Courses in Mathematics and Science

Mathematics	Total	Male	Female	White	Black	Hispanic
Algebra I	76.3	75.3	77.2	77.7	70.7	73.1
Geometry	61.5	61.2	61.7	65.1	44.0	40.2
Algebra II	47.1	45.8	48.4	51.9	32.4	30.2
Trigonometry	19.0	20.3	17.8	20.9	10.9	9.9
Analysis or Pre-Calculus	12.8	14.0	11.6	13.5	5.1	7.4
Calculus	6.2	7.7	4.7	5.9	2.3	3.6
Any remedial or below-grade course	24.9	26.7	23.2	20.6	46.5	42.5
Science						
	Total	Male	Female	White	Black	Hispanic
Biology	88.3	87.0	89.6	89.2	86.2	85.4
Chemistry	44.8	45.9	43.7	47.7	29.8	29.4
Physics	19.5	24.6	14.8	20.9	10.1	9.8

Source: Kolstad, A., and J. Thorne. (1989). "Changes in High School Course Work from 1982 to 1987: Evidence from Two National Surveys." Paper presented to the annual meeting of the American Educational Research Association, San Francisco, Calif., March 27, 1989.

found enrollments in advanced science courses in the United States to be, proportionately, well below other industrialized nations (Mullis et al. 1990, citing the International Association for the Evaluation of Educational Achievement 1988).

The United States' practice of reserving some important topics in mathematics and science until students can opt out of learning about them is far from universal. Contrasting the U.S. mathematics curriculum with that in the Soviet Union, Robert Nielson (1990) notes:

> Instead of teaching arithmetic for nine years as we do . . . the Soviets teach arithmetic, combined with an introduction to intuitive geometry and other mathematical domains (probability, algebra, etc.) in five years. Whereas our students are effectively introduced to and taught geometry in one fell swoop, at a fairly advanced level, usually in 10th grade—an attempt that does not breed success—Soviet students have completed intuitive geometry by grade 5, studied semirigorous plane geometry in grades 6-8, and solid geometry (something most of our students barely encounter) in grades 9-10.

Moreover, advanced high school science and mathematics courses in other nations frequently contain material that is not present even in Advanced Placement courses taken by top U.S. students (Nelkon and Parker 1988, Dacre 1989).

One of the most consistent findings from international studies—albeit a rather obvious one—is that students won't test well on topics they've never been taught in class (McKnight et al. 1987, International Association for the Evaluation of Educational Achievement 1988, LaPointe et al. 1989).

Effects of Tracking

The widespread practice in the United States of tracking students into ability groups means many pupils will never be exposed to some mathematical or scientific topics or expected to solve authentic problems before leaving school. For example, *The Underachieving Curriculum* (McKnight et al. 1987), a report on SIMS,

identified four quite different mathematics programs offered by U.S. schools to 8th graders, ranging from grade-school arithmetic to algebra. The report notes that "as early as the junior high school grades, tremendous differences are created in what mathematics U.S. children have the opportunity to learn and, therefore, in what they are able to achieve. These differences in opportunity set boundaries on the degree to which individual students are able to reach their fullest potential, boundaries that leave less to reward individual efforts than in any of the other countries for which data were available."

The latest data from the National Assessment of Educational Progress (NAEP) confirm the disparities in content experienced by students of similar ages: 89 percent of high-ability 8th graders receive a heavy emphasis on algebra, while 60 percent of low-ability 8th graders get a heavy emphasis on numbers and operations (Mullis et al. 1991).

Although the separation of students into tracks may not be a barrier to high student achievement in and of itself, the disparities in resource allocation to students in the various tracks all too often undermines success for those placed in the lower tracks.

Impact on Underrepresented Groups

While the failure of many U.S. students to take advanced mathematics and science courses is alarming, the underrepresentation of black and Hispanic students is particularly distressing. As Figure 2.1 shows, black and Hispanic students are significantly less likely to take advanced mathematics and science coursework than are white students. Moreover, the gap between black and white students' achievement in mathematics and science, while narrowing, is still substantial. NAEP tests of mathematics and science achievement have found that the performance of black and Hispanic 17-year-olds is comparable to that of white 13-year-olds (Mullis et al. 1990).

Although students and their parents hold some power to ensure that advanced science and mathematics courses are taken, there is evidence that pupils' "opportunity to learn" mathematics and science (including access to content, high expectations, well-qualified teachers, adequate materials, equipment, etc.) is

particularly low in schools serving high numbers of minority or disadvantaged youth. "Low-income African-American and Hispanic students enrolled in secondary schools where they are the majority have less extensive and less demanding science and mathematics programs available to them," according to *Multiplying Inequalities* (Oakes 1990), a study by the RAND Corporation. For example, among middle and junior high schools terminating in 8th grade and consisting of 90 percent or more minority enrollment, only about 30 percent offered an algebra course, implying that not a single student in the other 70 percent of those schools was ready to take algebra during 8th grade (or, by extension, calculus in 12th grade). Moreover, students placed in low-ability tracks, regardless of school type, had fewer opportunities to learn than did students in higher tracks. The study reports that, "Because school officials judge so many low-income and minority students to have low ability, many of these students suffer the double disadvantage of being in schools that have fewer resources and classrooms that offer less access to knowledge."

The United States must increase efforts to ensure that all students have access to a comprehensive K-12 mathematics and science program that includes the skills and knowledge they'll need for informed citizenry or advanced study. Special efforts must be made to reach those presently underserved.

The mathematics and science curriculums experienced by most U.S. students—as well as the textbooks and assessments linked to those curriculums—fail to reflect the "frontiers of knowledge" about how children learn best.

Although the U.S. education system's failure to ensure that all students receive sufficient instruction to provide a deep and rich grounding in mathematics and science is troubling, just as problematic is the inadequacy of the curriculum itself. Too often, the mathematics and science curriculums in the United States are not demanding, interesting, or useful enough to achieve their intended purposes. They sacrifice depth for coverage, don't take advantage of technologies such as hand-held calculators, fail to make meaningful connections among the disciplines, and generally ignore students real-life experiences and cognitive development.

The National Council of Teachers of Mathematics (NCTM 1989) reports that half of all mathematics has been invented since World War II. Yet at a recent gathering of the Mathematical Sciences Education Board (MSEB), Thomas Romberg of the University of Wisconsin-Madison described the organization of the typical U.S. mathematics curriculum as "eight years of 15th century arithmetic, followed by one year of 17th century algebra, followed by one year of 3rd century B.C. geometry." And the topics are not necessarily well-chosen. "The traditional mathematics curriculum focuses too narrowly on a few topics of limited appeal and utility—on arithmetic, which leads to algebra, which in turn leads to calculus," writes Lynn Steen (1989). "Most students would benefit from a curriculum with a broader vision . . . " including, for example, more on estimation, chance, measurement, symmetry, data, algorithms, and visual representations.

Again, such curricular constraints are not found in other nations. *The Underachieving Curriculum* (McKnight et al. 1987) noted that while many U.S. 8th graders are experiencing "a great deal of repetition and review, with . . . topics covered with little intensity," French students are already learning about geometry, and the Japanese curriculum stresses algebra.

The situation is little better in science. Noting deficiencies in the presentation of mathematics, science, and technology, *Science for All Americans*, a report of the American Association for the Advancement of Science (Rutherford and Ahlgren 1990), asserts that:

> The present curricula in science and mathematics are overstuffed and undernourished. Over the decades, they have grown with little restraint, thereby overwhelming teachers and students and making it difficult for them to keep track of what science, mathematics, and technology is truly essential. Some topics are taught over and over again in needless detail; some that are of equal or greater importance to scientific literacy—often from the physical and social sciences and from technology—are absent from the curriculum or are reserved for only a few students.

Outmoded Theory and Practice

Curriculum and instruction in the United States is frequently influenced by outmoded theory and practice: for example, the assumptions that teachers should base instruction hierarchically from discrete sub-skills to higher-order thinking, or that content is learned through teachers' talking and students' passive listening. "Constructivism," one of the most talked-about (but not necessarily practiced) influences on current learning theory, holds that:

> Learning is not a process of passively absorbing information and storing it in easily retrievable fragments as a result of repeated practice and reinforcement. Instead, students approach each new task with some prior knowledge, assimilate new information, and construct their own meanings. Furthermore, ideas are not isolated in memory but are organized and associated with the natural language that one uses and the situations one has encountered in the past (National Research Council 1990, citing Resnick 1987).

However, U.S. mathematics and science classrooms too often promote a passive role for students, depending heavily on textbooks, teacher talk, and worksheets. Less frequently used are activities that could lead to a more active student role, such as setting up and solving authentic problems, experimenting, or working in small groups (Mullis et al. 1991, LaPointe et al. 1989).

U.S. curriculums, textbooks, and assessments are more often than not built with a "scatter-shot" organization in which topics are raised briefly and dropped without connections and low-level skills are repeatedly emphasized. "The curricula of other countries reflect very different beliefs about what children are capable of learning," according to *Reshaping School Mathematics* (National Research Council 1990). "American textbooks tend to develop ideas very slowly by progressing through a hierarchy of small, straightforward learning tasks. Texts from Asian countries and from the Soviet Union immerse students in much more demanding problem situations from the beginning" (National Research Council 1990, citing Fuson et al. 1988). *The Underachieving Curriculum* (McKnight et

al. 1987) notes that U.S. curriculums feature more "single lesson concepts," designed to be taught in one or two lessons before moving on to a different topic, and adds that this approach typically is not seen in other countries, especially the high-achieving ones such as Japan.

There is some evidence, moreover, that Asian elementary mathematics classrooms are more likely than those in the United States to contain some of the very elements of good classroom practice endorsed by U.S. experts. Stigler and Stevenson (1991) note that it is not uncommon for Asian teachers to focus an entire class period on a single problem, to make linkages to students' previous experiences, and to keep instruction focused on problem solving (for example, by beginning with a real-life example and delaying the introduction of unfamiliar terminology or operations until students have concrete experiences). Indeed, the common stereotype of Asian nations as favoring rote learning and de-emphasizing problem solving appears to be unwarranted. "We find little merit to the argument that Asian students acquire their skills in mathematics through rote learning and that they excel primarily in the solution of problems that depend on automatic, routinized solutions," report Stigler and colleagues (1990). "In fact, it was the American children who tended to approach problems in a stereotyped manner."

Mathematics and science curriculums in the United States, and the assessments and textbooks tied to them, must be revised to reflect new ideas about how children learn. This revision should ensure that all children have greater access to a broad range of mathematical and scientific topics as well as a curriculum that fosters complex thinking and work on authentic problems.

For a variety of reasons, instructional quality in mathematics and science does not reflect the need for all students to master challenging content.

Teachers in the United States are not necessarily less prepared to teach content than their counterparts in other nations (McKnight et al. 1987) Nonetheless, some available evidence about the preparation, in-service opportunities, and support for some U.S. teachers raises concerns. Further, regardless of the qualifications our teach-

ers bring with them into classrooms, the instruction provided there too often reflects an outmoded view of how mathematics and science should be taught and learned.

Only one in three elementary teachers meets the National Science Teachers Association's (NSTA) recommended standards for elementary science teachers, and just one in five elementary teachers meets comparable standards in mathematics outlined by the NCTM. Further, elementary teachers report feeling much less qualified to teach science than they do to teach reading, math, or social studies (Weiss et al. 1989). The latest NAEP mathematics report (Mullis et al. 1991) notes that, "Although the *NCTM Standards* call for elementary teachers to build the foundation for students' further study in geometry, probability and statistics, and algebra, it appears that the majority of elementary teachers have had no courses in these content areas.

At the secondary level, data gathered by the CCSSO across 30 states found that the percentages of teachers assigned to teach a subject for which they are not certified is 9 percent for mathematics, 8 percent for biology and chemistry, and 12 percent for physics (Blank and Dalkilic 1991). Approximately one in three junior high school science teachers and one in six high school science teachers has neither a degree in science nor a degree in science education (Weiss et al. 1989).

Working Conditions

Nor does the working environment have much to offer U.S. teachers. Says *Science for All Americans* (Rutherford and Ahlgren 1990): "Teachers of science and mathematics have crushing teaching loads that make it nearly impossible for them to perform well, no matter how excellent their preparation may have been." Compared with Japanese teachers, U.S. teachers enjoy less planning time to prepare for classes (McKnight et al. 1987, Stigler and Stevenson 1991) and, too frequently, staff development for U.S. teachers is marginalized or neglected altogether. At least one in four mathematics and science teachers in grades 7-12 reports having taken no college courses in the past 10 years (Weiss et al. 1989). And while others earning college degrees in mathematics, science, and engineering go on to generally higher-paying jobs with better working

conditions, teachers too often operate with no phones, minimal clerical help, scarce resources, and few opportunities for advancement.

A variety of other working conditions also affect teaching quality—the time allotted during the school day for actual science and mathematics instruction, class size and teaching load, teachers' opportunities for collaboration and decision making, and teacher salary (Gilford and Tenenbaum 1990). These are all practices over which school administrators and school boards have some control.

Given the constraints regularly confronting U.S. teachers, it shouldn't be surprising that instruction sometimes lacks creativity, fails to engage students, and falls short of best practice. International studies in mathematics and science (McKnight et al. 1987, LaPointe et al. 1989) and a synthesis of U.S. studies over two decades (Harms and Yager 1981) have confirmed what John Goodlad (1984) found in his pathbreaking book, *A Place Called School*: Textbooks and teacher talk dominate most classrooms. "Honest questions by teachers are rare in mathematics classrooms," reports *Everybody Counts* (National Research Council 1989). "Most teachers ask rhetorical questions because they are not so much interested in what students really think as in whether they know the right answer." Many students, as a result, "consider mathematics primarily a matter of rules and memorization" (McKnight et al. 1987).

The Underachieving Curriculum draws a connection between the lack of inventive teaching and the conditions educators frequently face. "It is reasonable to conclude that there are many factors at work, including the constraining effects of demanding workloads and the lack of professional support within school systems, that mitigate against teachers exhibiting the best practice that they are currently prepared to offer" (McKnight et al. 1987).

If instruction in U.S. mathematics and science classrooms is to reflect "best practice," teachers' preparation, professional development, on-the-job support, and working conditions must be improved.

Cultural values, attitudes, the media, and other factors contribute to a belief that, for many students, high achievement in mathematics and science is either not worth striving for or unattainable.

Whereas most Americans would attempt to hide a reading problem or lack of historical knowledge, ineptitude in mathematics and science is often worn as a perverse badge of honor. "I'm just no good in math," has become a familiar refrain to Americans, and media depictions of "mad scientists" and "computer geeks" reinforce the notion that only a few people with natural talent can achieve at high levels in mathematics and science. These feed into low expectations on the parts of parents, teachers, and students themselves about how much mathematics and science large numbers of students are likely to attain. Such perceptions are reflected in the insufficient numbers of students taking the advanced mathematics and science courses necessary to achieve at high levels.

Cultural beliefs also contribute to our "gender gap" in mathematics and science coursetaking and achievement. At the secondary level, female students are slightly less likely to take courses in trigonometry, analysis/precalculus, calculus, chemistry, and physics than their male counterparts (Kolstad and Thorne 1989). Not surprisingly, female 17-year-olds score lower than males on mathematics and science tests administered by the NAEP (National Center for Education Statistics 1991a). Moreover, females who received mostly A's in high school and who took calculus graduated from college with degrees in mathematics, science, and engineering less frequently than males with similar backgrounds. Almost twice as many male college graduates (34 percent) as female graduates (18 percent) stated in high school that they intended to major in science, engineering, or mathematics in college (National Center for Education Statistics 1991b).

Research by Harold Stevenson and colleagues (1986) has noted other cultural beliefs that may play a part in the low achievement of U.S. students relative to other nations. Compared to their Asian counterparts, American students and their parents appear more likely to attribute success in mathematics to innate talent than to effort. Moreover, a survey of high school sophomores by the Public Opinion Laboratory (1988) at Northern Illinois University found that 40 percent reported that their parents did not think

mathematics was a "very important subject" and 57 percent gave a similar negative response about the importance of science.

In addition to this basic lack of support, the United States, compared to some other nations, is missing some of the incentives to encourage students to take rigorous coursework in mathematics and science or to achieve at high levels. Economist and ASCD panel member John Bishop (1990) asserts that; "Many of the weaknesses of mathematics and science curriculums—the constant review and repetition of old material, the slow pace, and minimal expectations—are adaptations to the low level of effort most students are willing to devote to these subjects." There is evidence that peers actively discourage high mathematics and science achievement (it wrecks the grading "curve"), that only the most selective colleges and universities demand high entrance exam scores in mathematics (and frequently none in science), and that the labor market does not recognize job applicants for high school mathematics and science achievement. In other industrialized nations, achievement tests that include content in mathematics and science are critical to entrance into higher education. In Japan, clerical, blue collar, and service jobs at the most prestigious firms are available only to students who are recommended by their high schools, and such decisions are made largely on the basis of grades and exam scores (Bishop 1989).

U.S. students are unlikely to achieve world-class standards in mathematics and science if only a few are expected, encouraged, or required to take rigorous coursework or to demonstrate a high level of proficiency.

3

Recommendations for Improving U.S. Achievement in Mathematics and Science

The agenda for reforming U.S. mathematics and science education must be two-fold: (1) to raise the achievement of *all* students to a level now accomplished by relatively few, and (2) to increase the quantity and quality of the "pool" from which future specialists in mathematics, science, and engineering are drawn.

Recent national efforts to improve mathematics and science achievement in the United States reflect the need to help all students achieve a common core of understandings. "The focus of school mathematics is shifting from a dualistic mission—minimal mathematics for the majority, advanced mathematics for a few—to a singular focus on a significant common core of mathematics for all students," according to *Everybody Counts* (National Research Council 1989). One purpose of the AAAS Project 2061 is to put into place curriculums that address the "understandings and habits of mind . . . essential for *all* (author's emphasis) citizens in a scientifically literate society" (Rutherford and Ahlgren 1990).

Japan has shown that the goal of increasing access to education and achieving high results need not conflict, raising its high school completion rate from 57 percent to 92 percent between the First (1964) and Second (1982) International Mathematics Studies while also posting achievement scores among the best in the world (McKnight et al. 1987). But the United States is likely to raise the achievement of its students only by addressing a broad range of issues: curriculum, standards, assessment, teaching/teacher preparation, and public support. What follows are the panel's recommendations on needed steps in these areas.

Curriculum

The United States must substantially upgrade mathematics and science curriculums to reflect current knowledge and to simultaneously address concerns about excellence and access.

The expectations that Americans have of their schools are rising. The number of students from groups that have traditionally been most poorly served by the education system—minorities and the underprivileged, in particular—has risen, and will likely continue to do so. Meanwhile, schools are being asked to prepare these students and their majority cohorts to a level now achieved by relatively few. Mathematics and science curriculums must hold as a basic premise that all students can attain important common understandings and competencies.

Toward this goal, we believe that all students should be required to take mathematics and science throughout their precollegiate education, including a full four years in grades 9-12. But we must bear in mind the fact that, as the school reforms of the 1980s illustrated, increasing the time students spend learning mathematics and science will not, in and of itself, produce higher achievement, particularly if courses are of poor quality (Clune et al. 1989). Therefore, mathematics and science coursework should not be watered-down academic fare but material pitched at a level that reflects high expectations for all students. The United States is unlikely to increase student achievement, or improve its international standing, without allowing more class time for studying topics in depth and giving students more chances to initiate learning activities.

Recently, several professional groups have begun to redesign mathematics and science curriculums, bringing them more into line with cognitive learning theory. Though each takes a different approach, the NCTM's Curriculum Standards Project, the AAAS' Project 2061, and the NSTA's Scope, Sequence, and Coordination of Secondary Science Project share some common elements derived from this theory. They support, for example, more study of real-life problems, introduction of some topics or subjects (such as statistics or physics) earlier in the K-12 program, greater depth, increased use of technologies and hands-on activities, and more cross-

disciplinary content. We believe that these projects are a step in the right direction, and we urge that the body of knowledge and competencies that all students must know and be able to demonstrate in mathematics and science be much higher than is now common, perhaps equal to that of the Advanced Placement programs, which currently serve relatively few students.

We believe that the organization of the curriculum and the materials that support it must be revised substantially to come into line with new knowledge about how children learn best. In sum, science and mathematics curriculums should:

- connect what is taught in mathematics and science classrooms to applications outside the classroom, for example local community, national, and global issues at the intersection of science, technology, and society (Cheek in press, NSTA 1990);
- take advantage of technologies, such as hand-held calculators and manipulatives in mathematics and design, modeling true experimentation activities in science (Woolnough 1991, Steffe and Wood 1990);
- appropriately integrate science and mathematics principles, concepts, and applications across school subject areas, including technology education, humanities, and the arts (Rutherford and Ahlgren 1990, NSTA 1990, National Research Council 1990, International Technology Education Association 1988, Savage and Sterry 1991); and
- tap the inventiveness and natural curiosity of young children in mathematics and science learning through such endeavors as "children's engineering" and "invention conventions" (Dunn and Larson 1990).

Standards

The United States must establish mathematics and science standards that influence curriculum, instruction, and assessment to promote higher student achievement.

Educators and policymakers have recently become increasingly convinced of the need to develop consensus standards to guide school curriculums, instructional practices, and assessment. The catch phrase in the debate over school instruction in various

content areas has become "What should students know and be able to do?" Closely related are the basic (but equally complex) questions of "What best measures what students know and are able to do?" and "What should teachers know and be able to do?" Each of these questions suggests the need for common agreement on appropriate levels of performance.

Many of the current measures of what students and teachers have attained fall short of the high standards needed to improve mathematics and science education. Students may fulfill course requirements even while exerting little effort and earning passing marks on examinations of low-level skills. In many schools, the diploma signifies little more than that students have occupied seats in appropriate classrooms for the requisite number of hours. Similarly, the entry of teachers into the profession frequently depends on seat time in various courses, supplemented with superficial assessments of a candidate's teaching skill and mastery of appropriate content.

Several groups have begun to move toward defining national standards to address this lack of clarity. The NCTM, through a consensus-building process, has issued major reports recommending national standards for mathematics curriculum, evaluation, and teaching (NCTM 1989, 1991). And, as this report went to press, active efforts were under way at the National Research Council and the NSTA to see that consensus-backed standards for K-12 science are designed as quickly as possible. Additionally, the National Board for Professional Teaching Standards (1989) is in the process of developing a new national voluntary system of professional certification for well-qualified teachers.

Recent political developments are likely to decrease the time frame for the development of these national standards. As a result of the effort to develop and monitor national goals for education, President Bush and the nation's governors have set into motion a process to create standards in five basic school subjects, including science and mathematics. The National Education Goals Panel (1991), a bipartisan task force that includes representatives of the Bush administration, state governors, and Congress, has called for development of a "national educational standards framework"—created by a representative standards board and informed by the

work of national curriculum study groups, state curriculum frameworks, and the curriculum frameworks of other countries. This framework is designed to illustrate what students need to know and be able to do as a result of their schooling. The standards can be used to create a set of national "anchor exams" (the use of which would be voluntary) or to guide the development of state assessments. In addition, the National Council on Education Standards and Testing is now preparing recommendations about a process for creating national standards and a voluntary system of assessments to accompany them.

We believe that the work of the NCTM, with its emphasis on consensus building, is a model for the development of national standards. But, useful as standards are, we must recognize that carefully articulated statements unaccompanied by targeted resources are likely to accomplish little. At the local, state, and federal levels, resources must be targeted to support the "new consensus" about the mathematics and science needed by all students. Textbooks, tests, and teaching activities must all come in line with the vision represented in these new standards.

Although we do not take a position on any of the current proposals for new national achievement tests, we do urge that any test, at either the state or national level, be based upon the consensus standards developed for mathematics and science. Further, we support the development of international standards in mathematics and science, a process that may evolve from the International Educational Indicators project of the Organization for Economic Cooperation and Development (OECD) . One activity under this project addresses student outcomes. Objectives of this activity include: (1) development of a comprehensive analytic framework for educational achievement outcomes—covering curricular cognitive achievements (subject matter learning), cross-curricular cognitive achievements (general critical thinking skills), and affective achievements (positive values and self perceptions), and (2) development of a set of specifications that might be used by the OECD to obtain achievement outcome data on a regular basis.

Assessment

Policymakers and educators should promote the responsible use of student assessments that bring about positive changes in curriculum and instruction, and provide indications of student achievement.

Educators are nearly unanimous in noting that student assessment has a powerful influence on the range of content and instructional strategies common in classrooms (Darling-Hammond 1991). Assessments quickly become central in the development of textbooks, the selection of teaching strategies, and the public's and policymakers' notions about which programs "work best." The quality of assessments used, then, is likely to make a key difference in whether attempted reforms foster or thwart positive change.

"We must ensure that tests measure what is of value, not just what is easy to test," notes *Everybody Counts*. "What is tested is what gets taught. Tests must measure what is most important" (National Research Council 1989). Much progress must be made before most standardized tests are likely to achieve this goal. Standardization of assessment instruments requires that the instrument be used to gather data on a large sample. Assessment exercises that effectively measure what is most important are in the process of being developed. Those that have already been developed are expensive to administer and difficult to score. Thus cost is a central issue in the design of standardized tests that assess higher-level mathematics and science competence.

The most common mass tests in use are better at assessing the attainment of low-level skills than they are at assessing students' reasoning skills or their ability to apply what they've learned in novel situations. For example, the NCTM Standards are widely accepted as representing a consensus vision for high-quality mathematics programs. Yet one analysis of six commonly used standardized tests for 8th grade found that the assessments depended heavily on computing based on algorithmic procedures and did not address any of the four primary standards: problem solving, communication, reasoning, and connections (Romberg et al. 1991). Tests of lower-level skills do yield some valuable information, but too often these types of tests—especially when linked to such actions as the public ranking of schools by test scores—limit

the range of topics and activities that educators might normally teach, thus limiting the power of the curriculum and the professional judgment of teachers (Darling-Hammond 1991).

Given the high stakes associated with the outcomes of student assessment (e.g., perceptions about program quality, sanctions for low-performing students), many of the strategies outlined in this paper depend heavily on better types of measures than the currently available multiple-choice standardized tests. We believe that a substantial investment must be made to develop better assessment technologies. Assessment programs that increase the use of "performance tasks" (in which students actually conduct, for example, a science experiment), portfolios, or constructed-response items should be encouraged and funded at levels commensurate to the importance of the task (Wolf et al. 1991). Schools in the United States should also take better note of efforts and insights from alternative assessment work in other nations (e.g., Riding and Butterfield 1990). However, new criteria will be needed for judging the quality of performance-based assessments. One important quality dimension is the generalizability of performance assessments, and research is under way on this aspect of performance assessment (Baxter et al. in press) as well as validation criteria.

Teaching/Teacher Preparation

To foster more innovative instruction, the United States must take aggressive actions to improve the preparation of mathematics and science teachers and increase their on-the-job support.

One requirement for putting into place high-quality mathematics and science programs for all students is substantial upgrading of the preparation, support, and competence of teachers in these fields (National Research Council 1990, NSTA 1990). If more students are to increase their study of mathematics and science, as we urge, the United States must prepare more teachers in these fields while also raising their level of competence to provide more powerful and appropriate instruction.

A developing body of research substantiates the long-held belief that teaching is a complex activity, requiring expert knowledge in a content area *and* the ability to make decisions based on contex-

tual factors in the classroom, such as students' experiences, cultural variables, and the specific nature of the content itself (Shulman 1986). Both the requirements for becoming a mathematics or science teacher and the means for evaluating teacher competence should reflect this complexity.

The professional development of science and mathematics teachers must continue throughout the teachers' educational and professional life. The development of attitudes about teaching as a profession and beliefs about what constitutes good science and mathematics pedagogy begins with early experiences in the primary and secondary schools, is informed by undergraduate and professional education, and is tempered by the fires of practice.

Formal professional education typically begins late in the undergraduate experience or is concentrated in a postgraduate year. Because of the separation of subject matter instruction from professional education, fledgling teachers do not have the opportunity to integrate their content knowledge with the psychological and sociological content they learn in professional education courses. Preservice teachers learn educational theory in the rarified environment of higher education, untempered by the often harsh realities of schools.

Once in the classroom, the beginning teacher takes on all of the responsibilities of a veteran with little or no mentoring. Because of certification regulations and district compensation policies, classroom teachers have little motivation or incentive to return to the university to update subject matter knowledge, to become informed about developing theories of learning and their implications for teaching, or to broaden their educational competence. Consequently, after becoming permanently certified, teachers' skills and knowledge often remain static.

While schools of education are often criticized for science and mathematics teachers' poor academic and professional education, the academic departments in science and mathematics must share the blame. Science and mathematics are essential elements of the undergraduate education of all teachers, not just those who will teach science and mathematics. Taught either as general education courses or courses for science and mathematics majors, college

level mathematics and science courses should model exemplary pedagogical practice.

Teacher education programs must better prepare science and mathematics teachers to make connections between the real world and these subject areas and to effectively engage students in challenging cognitive work. Organizations such as the Holmes Group have taken a positive step in this direction by specifically recognizing science and mathematics understanding as critical to effective teacher preparation. For example, according to the Holmes Curriculum Committee (Holmes Group 1991), teachers should "understand mathematics as a way of representing real-world problem situations in mathematical terms . . . and know how to validate the answers of predictions." Of science, the committee wrote: "Every teacher needs to understand the natural world and how it operates. . . . Most important, their laboratory sections should be experiences of scientific method, developing dispositions and techniques for inquiry and problems solving."

We believe that the following steps would represent a major commitment to improving teacher competence and the use of more innovative instructional strategies in mathematics and science than are currently the norm:

- Professional education schools and departments of mathematics and science should work to redefine their programs to support the broad science and mathematics literacy goals outlined by the Holmes Group and others.
- Districts and schools should implement policies that promote teaching quality (e.g., allot adequate time for science and mathematics instruction, limit class size and teaching load to a reasonable size, and provide opportunities for teacher collaboration and decision making).
- Districts should offer long-term, frequent staff development to teachers of mathematics and science.
- Mathematics and science teachers should continue their education to keep abreast of developments in their field. We suggest a requirement of ten course units of higher education in the content area each five years.
- Emergency licensing of teachers in mathematics and science should be eliminated.

Public Support

Raising U.S. achievement in mathematics and science will require systemic changes that will come about only through dialogue and concerted effort from leaders within and outside the education community. Accomplishing this goal means both increasing the perceived importance of higher mathematics and science achievement and *implementing policies and practices that support this belief.*

The past decade of school reforms has brought into focus a paradox. In report after report, prestigious commissions have lamented low student achievement in various content areas (including mathematics and science), but the general public does not seem alarmed. Polls consistently show that the public is generally satisfied with schools, particularly those schools closest to the respondent's home. Further, Stevenson and Stigler's (1986) research found that although American students were outperformed by their Asian peers, American parents were significantly more satisfied with the performance of the schools attended by their children.

In the American tradition, local decisions are held in high esteem. Unlike many other nations, the United States has no dominant federal education ministry, no national curriculum, no nationally mandated textbooks, and no comparable national tests. These facts alone dictate the need for broad participation in setting the direction for needed changes in mathematics and science programs. Among the myriad levels of support, we see the following actions as especially important:

• *Gather and disseminate appropriate data on the performance of students in mathematics and science and the factors contributing to their performance.* The CCSSO, for example, is collecting information from most states on a host of important indicators, including percentages of students taking key academic courses and teacher qualifications. The new School and Staffing Survey conducted by the National Center for Education Statistics is also a rich source of data on teacher qualifications and teacher supply/demand for both public and private schools. We believe that local schools should make use of such data in addition to gathering their own information about who is or is not receiving services from their science and

mathematics programs. Employers, college officials, and former students can be surveyed about the extent to which schools are delivering the mathematics and science curriculums needed for life after graduation.

• *Identify needed changes that will support raising student achievement in mathematics and science.* There needs to be serious discussion at the local, state, and national levels about the causes and consequences of low mathematics and science achievement and what changes are needed to improve the situation. One effort to foster such conversation is the MSEB's work supporting coalitions in numerous states that bring together educators, business leaders, and public policy representatives. In science, the Triangle Coalition for Science and Technology Education encourages the formation of local partnerships between business, industry, federal laboratories, university research labs, and local schools.

• *Work more closely with parents, employers, higher education officials, and others to improve the cooperation and articulation between the various levels of the educational systems in the United States, including the informal sector.* High levels of U.S. mathematics and science achievement will require better cooperation between formal educational systems and the informal education sector. Science and technology museums offer excellent facilities and programs for school-aged children and adults to expand their knowledge and awareness of science and mathematics. Other partners such as the National 4-H Program, Cooperative Extension Programs in all 50 states, the Boy Scouts, and the Girl Scouts, to name a few, all offer learning programs involving science and mathematics.

Increasing parental commitment to improved mathematics and science education can be fostered through programs that directly involve parents in mathematics and science learning *with* their children. The Family Math program of the Lawrence Hall of Science, the "Say Yes" Project of the National Urban Coalition, and the Parents and Children for Terrific Science Education Project of the American Chemical Society are several examples of such programs.

In addition, public support is needed to help change the fact that mathematics and science achievement of persons who do not enter careers in these fields generally goes unrewarded. Panel

member John Bishop's research suggests that school achievement in mathematics is related to on-the-job productivity in later jobs. Yet employees do not reward this achievement with higher pay (Bishop 1990). We believe that schools and employers should work together more closely to find ways to improve the flow of information on student achievement from schools to businesses and to reward students who perform well in mathematics and science. Colleges can do their part by requiring applicants to present evidence that they've mastered a comprehensive and rigorous curriculum in mathematics and science.

- *Target appropriate resources commensurate to the task of significantly improving the U.S. system of mathematics and science education to foster higher student achievement.* "Money follows commitment," noted panel member Dorothy Strong. Local, state, and national leaders must determine both their current allocations for mathematics and science instruction and whether these allocations match the importance they place on raising achievement in these essential fields.

In holding out the goal of mathematic and scientific literacy for all, we may be more limited by our will and commitment than by our knowledge of what needs changing. "It is *not* naive to have such expectations and beliefs in the capacities of our children and young people," Shirley Hill (1991) told a recent meeting of the MSEB. "Any educator who does not hold that belief ought to go into some other line of work. What this ambitious objective does is challenge *our* imaginations, *our* creativity, and most of all, *our* will."

Appendix: Executive Summary

Despite rising concerns about the mathematics and science achievement of U.S. students, a flood of evidence amassed over the past decade suggests that far too few students are receiving the high-quality education needed in these subjects either for careers or for basic citizenship.

Relatively low percentages of U.S. students, even those on the brink of graduation, are able to answer moderately difficult questions in mathematics and science that require reasoning and problem solving. Many students never take an advanced course in mathematics or science, with assessment results and coursetaking figures even lower for minority students than for their white peers.

Several international studies of student achievement in mathematics and science have fueled interest in improving the United States' underachieving system of education in these subjects. Almost without exception, U.S. students achieved, at best, a middle ranking compared to their counterparts in selected nations. This standing holds true across content areas and grade levels from arithmetic to calculus, earth science to physics, elementary school students to high school seniors. At its worst, the achievement of U.S. students on certain topics and at certain ages is at the bottom of nations participating in various international assessments.

Among the key factors accounting for the low achievement of U.S. students in science and mathematics are the curriculum and instructional and material resources available to students (as well as their propensity to take advantage of them). Curriculums are often ill-conceived and repetitious, textbooks overstuffed, teachers overburdened and (particularly in elementary school) underprepared, classrooms lacking in needed equipment, and students either tracked out of or disinclined to take high-level courses.

The low number of U.S. students mastering high levels of material in mathematics and science, some research suggests, reflects our entrenched belief that skills in these fields are the domain of a

few, and that "natural talent," rather than effort, is the key to success.

The Panel's Findings

The ASCD Panel on U.S. Achievement in Mathematics and Science cited the following factors for the low achievement of U.S. students on national and international tests:

- Inadequate instruction in mathematics and science in grades K-12 for students to achieve at desired levels. This problem is particularly acute among underrepresented populations.
- The mathematics and science curriculums experienced by most U.S. students, which fail to reflect the "frontiers of knowledge" about how children learn best.
- Instruction that does not reflect the need for all students to master challenging content.
- Cultural values, attitudes, the media, and other factors that contribute to a belief that, for many students, high achievement in mathematics and science is not worth striving for or is unattainable.

The Panel's Recommendations

According to the ASCD Panel, the agenda for reforming U.S. mathematics and science education is two-fold: (1) to raise the achievement of *all* students to a level now accomplished by relatively few and (2) to increase the quantity and quality of the "pool" from which future specialists in mathematics, science, and engineering are drawn. To help achieve these ambitious aims, the panel makes the following recommendations in the areas of curriculum, standards, assessment, teaching/teacher preparation, and public support:

Curriculum: The United States must substantially upgrade mathematics and science curriculums to reflect current knowledge and to simultaneously address concerns about excellence and access.

- All students should be required to take mathematics and science throughout their precollegiate education, including a full four years in grades 9-12.
- Support should be given to mathematics and science curriculums that:

- connect what is taught in mathematics and science classrooms to applications outside the classroom (e.g., local community, national, and global issues at the intersection of science, technology, and society)

- take advantage of technologies such as hand-held calculators and manipulatives in mathematics and design, modeling true experimentation activities in science

- appropriately integrate science and mathematics principles, concepts, and applications across school subject areas, including technology education, humanities, and the arts

- tap the inventiveness and natural curiosity of young children in mathematics and science learning through such endeavors as "children's engineering" and "invention conventions"

Standards: The United States must establish mathematics and science standards that influence curriculum, instruction, and assessment to promote higher student achievement.

- The standard-setting projects of the NCTM, with their emphasis on building consensus, should be a model for the various efforts now under way to set national standards in mathematics and science.
- At the local, state, and federal levels, resources must be targeted to support the "new consensus" about the mathematics and science needed by all students.
- Textbooks, tests, and teaching activities must all come in line with the vision represented in these new standards.
- The development of international standards in mathematics and science, a process that may evolve from the International Educational Indicators project of the Organization for Economic Cooperation and Development, should be supported.

Assessment: Policymakers and educators should promote the responsible use of student assessments that bring about positive changes in curriculum and instruction, and provide indications of student achievement.

- We believe that a substantial investment must be made to develop better assessment technologies. Given the high stakes associated with the outcomes of student assessment, many of the strategies outlined in this paper depend heavily on better types of measures than the currently available multiple-choice standardized tests. Assessment programs that increase the use of "performance tasks" (in which students actually conduct, for example, a science experiment), portfolios, or constructed-response items should be encouraged and funded at levels commensurate to the importance of the task (Wolf et al. 1991).

Teaching/Teacher Preparation: To foster more innovative instruction, the United States must take aggressive actions to improve the preparation of mathematics and science teachers and increase their on-the-job support.

- Professional education schools and departments of mathematics and science should work to redefine their programs to support the broad science and mathematics literacy goals outlined by the Holmes Group and others.
- Districts and schools should implement policies that promote teaching quality (e.g., allot adequate time for science and mathematics instruction, limit class size and teaching load to a reasonable size, and provide opportunities for teacher collaboration and decision making).
- Districts should offer long-term, frequent staff development to mathematics and science teachers.
- Mathematics and science teachers should continue their education to keep abreast of developments in their fields. We suggest a requirement of ten course units of higher education in the content area each five years.
- Emergency licensing of teachers in mathematics and science should be eliminated.

Public Support: Raising U.S. achievement in mathematics and science will require systemic changes that will come about only through dialogue and concerted effort from leaders within and outside the education community. Among the myriad levels of support, the following actions are especially important:

- Gather and disseminate appropriate data on the performance of students in mathematics and science and the factors contributing to their performance.
- Identify needed changes that support raising student achievement in mathematics and science.
- Work more closely with parents, employers, higher education officials, and others to improve the cooperation and articulation between the various levels of the educational systems in the United States, including the informal sector.
- Target appropriate resources commensurate to the task of significantly improving the U.S. system of mathematics and science education to foster higher student achievement.

References

Baxter, G.P., R.J. Shavelson, J.R. Goldman, and J. Pine. (in press). "Evaluation of Procedure-Based Scoring for Hands-On Science Assessment." *Journal of Educational Measurement*.

Bishop, J. (1990). "The Productivity Consequences of What is Learned in High School." *Journal of Curriculum Studies* 22, 2: 101-126.

Bishop, J. (1989). "Scientific Illiteracy: Causes, Costs, and Cures." In *This Year in School Science*, edited by Audrey Champagne. Washington, D.C.: American Association for the Advancement of Science.

Blank, R.K., and M. Dalkilic. (1991). *State Indicators of Science and Mathematics Education 1990*. Washington, D.C.: Council of Chief State School Officers.

Cheek, D. (In press). *Thinking Constructively About Science, Technology, and Society Education*. Albany: State University of New York Press.

Clune, W.H., P. White, and J. Patterson. (1989). "The Implementation and Effects of High School Graduation Requirements." Report published by the Center for Policy Research in Education, Rutgers, N.J.

Dacre, J. (1989). *Nuclear Physics*. Oxford, N.H.: Heinemann Educational Books.

Darling-Hammond, L. (June 1991). "The Implications of Testing Policy for Educational Quality and Equality." Paper presented at the conference on "Accountability as a State Reform Strategy: Impact on Teaching and Learning, Minority Issues, and Incentives for Improvement" convened by the American Educational Research Association, Washington, D.C.

Dunn, S., and R. Larson. (1990). *Design Technology—Children's Engineering*. Philadelphia, Pa.: The Falmer Press.

Fuson, K.C., J.W. Stigler, and K. Bartsch. (November 1988). "Grade Placement of Addition and Subtraction Topics in Japan, Mainland China, the Soviet Union, Taiwan, and the United States." *Journal for Research in Mathematics Education* 19: 449-456.

Gilford, D.M., and E. Tenenbaum. (1990). *Precollege Science and Mathematics Teachers: Monitoring Supply, Demand, and Quality*. Washington, D.C.: National Academy Press.

Goodlad, J.I. (1984). *A Place Called School: Prospects for the Future*. New York: McGraw-Hill Book Co.

Harms, N., and R. Yager, eds. (1981). *What Research Says to the Science Teacher, Vol. 3*. Washington, D.C.: National Science Teachers Association.

Hill, S.A. (April 1991). "The Vision: World Class Mathematics Education for Achieving the Nation's Goals." Speech to the National Summit on Mathematics Assessment convened by the Mathematical Sciences Education Board, Washington, D.C.

Holmes Group. (1991). *Toward a Community of Learning: The Preparation and Continuing Education of Teachers*. East Lansing, Mich.: The Holmes Group.

International Association for the Evaluation of Educational Achievement. (1988). *Science Achievement in Seventeen Countries: A Preliminary Report*. Elmsford, N.Y.: Pergamon Press.

International Technology Education Association. (1988). *Technology — A National Imperative*. Reston, Va.: International Technology Education Association.

Johnston, W.B., and A.H. Packer. (1987) *Workforce 2000: Work and Workers for the 21st Century*. Indianapolis, Ind.: The Hudson Institute.

Kolstad, A., and J. Thorne. (March 1989). "Changes in High School Course Work from 1982 to 1987: Evidence from Two National Surveys." Paper presented at the annual meeting of the American Educational Research Association, San Francisco, Calif.

Lapointe, A.E., N.A. Mead, and G.W. Phillips. (1989). *A World of Differences: An International Assessment of Mathematics and Science*. Princeton, N.J.: Educational Testing Service.

Madison, B.L., and T.A. Hart. (1990). *A Challenge of Numbers: People in the Mathematical Sciences*. Report of the Committee on the Mathematical Sciences in the Year 2000. Washington, D.C.: National Academy Press.

McKenzie, J.A. (October 31, 1990). "At Elementary Schools, The Task Will Be Finding Room for Science." *Education Week* 10, 9: 24-25.

McKnight. C.C., F.J. Crosswhite, J.A. Dossey, E. Kifer, J.O. Swafford, K.J. Travers, and T.J. Cooney. (1987). *The Underachieving Curriculum: Assessing U.S. School Mathematics from an International Perspective*. Champaign, Ill.: Stipes Publishing Co.

Miller, J.D. (February 1991). "The Public Understanding of Science in the United States." Paper presented at the annual meeting of the American Association for the Advancement of Science, Washington, D.C.

Mullis, I.V.S., J.A. Dossey, E.H. Owen, and G.W. Phillips. (1991). *The State of Mathematics Achievement: NAEP's 1990 Assessment of the Nation and the Trial Assessment of the States*. Princeton, N.J.: Educational Testing Service.

Mullis, I.V.S., E.H Owen, and G.W. Phillips. (1990). *America's Challenge: Accelerating Academic Achievement*. Princeton, N.J.: Educational Testing Service.

Mullis, I.V.S., and L.B. Jenkins. (1988). *The Science Report Card: Elements of Risk and Recovery*. Princeton, N.J.: Educational Testing Service.

National Board for Professional Teaching Standards. (1989). *Toward High and Rigorous Standards for the Teaching Professions*. Detroit, Mich.: National Board for Professional Teaching Standards.

National Center for Education Statistics. (1991a). *Digest of Education Statistics 1990*. Washington, D.C.: U.S. Government Printing Office.

National Center for Education Statistics. (1991b). *Who Majors in Science, Engineering, or Mathematics? College Graduates from the High School Class of 1980*. Washington, D.C.: U.S. Government Printing Office.

National Center for Improving Science Education. (1989). *Getting Started In Science: A Blueprint for Elementary School Science Education*. Washington, D.C.: National Center for Improving Science Education.

National Commission on Excellence in Education. (1983). *A Nation at Risk: The Imperative for Educational Reform*. Washington, D.C.: U.S. Government Printing Office.

NCTM. (1991). *Professional Standards for Teaching Mathematics*. Reston, Va.: National Council of Teachers of Mathematics.

NCTM. (1989). *Curriculum and Evaluation Standards for School Mathematics*. Prepared by the Working Groups of the Commission on Standards for School Mathematics. Reston, Va.: National Council of Teachers of Mathematics.

National Education Goals Panel. (1991). "Measuring Progress Toward the National Education Goals: Potential Indicators and Measurement Strategies." Report published by the National Education Goals Panel, Washington, D.C.

National Research Council. (1991). *Counting on You: Actions Supporting Mathematics Teaching Standards*. Washington, D.C.: National Academy Press.

National Research Council. (1990). *Reshaping School Mathematics: A Framework and Philosophy for Curriculum*. Washington, D.C.: National Academy Press.

National Research Council. (1989). *Everybody Counts: A Report to the Nation on the Future of Mathematics Education*. Washington, D.C.: National Academy Press.

NSTA. (1990). "Science Teachers Speak Out: The NSTA Lead Paper on Science and Technology Education for the 21st Century." *NSTA Handbook 1990-91*. Washington, D.C.: National Science Teachers Association.

Nelkon, M., and P. Parker. (1988). *Advanced Level Physics. 6th Ed.* Oxford: Heinemann Educational Books.

Nielson, R. (Spring 1990). "Anyone Can Learn Math: New Programs Show How." *American Educator* 14, 1: 29-34.

Oakes, J. (1990). *Multiplying Inequalities: The Effects of Race, Social Class, and Tracking on Opportunities to Learn Mathematics and Science*. Santa Monica, Calif.: The RAND Corporation.

Pelavin, S.H., and M. Kane. (1990). *Changing the Odds: Factors Increasing Access to College*. New York: College Entrance Examination Board.

Phares, T.K. (1990). *Seeking—And Finding—Science Talent: A Fifty-Year History of the Westinghouse Science Talent Search*. Abingdon, Va.: Westinghouse Electric Corporation.

Public Opinion Laboratory. (1988). *Longitudinal Study of American Youth: Base Year Codebook (Fall 1987-Spring 1988)*. Dekalb, Ill.: Public Opinion Laboratory.

Purves, A.C., ed. (1989). *International Comparisons and Educational Reform*. Alexandria, Va.: Association for Supervision and Curriculum Development.

Resnick, L.B. (1987). *Education and Learning to Think*. Committee on Mathematics, Science, and Technology Education; Commission on Behavioral and Social Sciences Education; National Research Council. Washington D.C.: National Academy Press.

Riding, R., and S. Butterfield, eds. (1990). *Assessment and Examination in the Secondary School*. New York: Routledge.

Romberg, T.A., L. Wilson, and M. Khaketla. (April 1991). "The Alignment of Six Standardized Tests with the NCTM Standards." Paper presented to the National Summit on Mathematics Assessment convened by the Mathematical Sciences Education Board, Washington, D.C.

Rutherford., F.J., and A. Ahlgren. (1990). *Science for All Americans*. New York: Oxford University Press.

Savage, E., and L. Sterry, eds. (1991). *Conceptual Framework for Technology Education*. Reston, Va.: International Technology Education Association.

Science Education News. (1991). Washington, D.C.: American Association for the Advancement of Science. 9, 5/6: 3.

Shulman, L. (1986). "Those Who Understand: Knowledge Growth in Teaching." *Educational Researcher* 15, 2: 4-14.

Steffe, L.P., and T. Wood, eds. (1990). *Transforming Children's Mathematics Education—International Perspectives*. Hillsdale, N.J.: Lawrence Erlbaum Associates.

Steen, L.A. (September 1989). "Teaching Mathematics for Tomorrow's World." *Educational Leadership* 47, 1: 18-22.

Stevenson, H.W., S.Y. Lee, and J.W. Stigler. (February 14, 1986). "Mathematics Achievement of Chinese, Japanese, and American Children." *Science* 231: 693-699.

Stigler, J.W., and H.W. Stevenson. (Spring 1991). "How Asian Teachers Polish Each Lesson to Perfection." *American Educator* 15, 1: 12-20, 43-47.

Stigler, J.W., S.Y. Lee, and H.W. Stevenson. (1990). *Mathematical Knowledge*. Reston, Va.: National Council of Teachers of Mathematics.

Thurgood, D.H., and J.M. Weinman. (1990). *Summary Report 1989—Doctorate Recipients from United States Universities*. Washington, D.C.: National Academy Press.

Weiss, I.R., B.H. Nelson, S.E. Boyd, and S.B. Hudson. (1989). *Science and Mathematics Briefing Book*. Washington, D.C.: National Science Teachers Association.

Wolf, D., J. Bixby, J. Glenn III, and H. Gardner. (1991). "To Use Their Minds Well: Investigating New Forms of Student Assessment." In *Review of Research in Education*, edited by G. Grant. Washington, D.C.: American Educational Research Association.

Woolnough, B., ed. (1991). *Practical Science*. Philadelphia, Pa.: Open University Press.

Association for Supervision
and Curriculum Development